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The

MAINTENANCE MANAGER

Collecting and Analysing Maintenance Data of Wind Turbines

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Acknowledgement

This report is part of the project entitled "*Development of a Maintenance Information System for Wind Turbines*" which has been carried out in co-operation with Baas & Roost Maintenance Consult BV and Lagerwey the WindMaster BV.

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SUMMARY

With the increasing maturity of wind energy, designers, manufacturers, owners and project developers are putting more and more emphasis on lowering the operational costs over the total lifetime in order to improve the economics of wind energy projects. Especially the economics of offshore wind parks depends heavily on the failure behaviour of the turbines. An adequate maintenance strategy in addition to a reliable design is very crucial for the economics of future wind energy projects. To develop such a maintenance stratey, it is necessary to have a clear understanding of the actual failure behaviour of the turbines and equipment in a wind park. In order to facilitate this need, the Netherlands Energy Research Foundation ECN and Baas & Roost Maintenance Consult BV have developed a database system the *Maintenance Manager* that enables management of regular maintenance, including the collection and analysis of failure and maintenance data. This development was carried out within the project "*Development of a Maintenance Information System for Wind Turbines*". The Maintenance Manager was programmed based on specifications drawn up in close co-operation with Lagerwey the WindMaster BV and other wind turbine manufacturers.

The most commonly used maintenance information systems enable the day-to-day maintenance planning, generate work sheets for technicians and are equipped with a logbook function. These modules are also present in the *Maintenance Manager* but in addition, the *Maintenance Manager* is equipped with unique features. These features offer wind turbine manufacturers the possibility to obtain maximal feedback from their failure and maintenance data with minimum effort.

- The Maintenance Manager is equipped with an FMECA module (*Failure Mode Effects and Criticality Analysis*) including libraries with FMECA's of commonly used wind turbine components and has the following advantages.
  - Failure modes and effects defined in the FMECA module provide the technicians with additional information on failures and increase the quality and simplicity of failure registration in less time.
  - The FMECA facilitates maintenance strategies based on the expected failure behaviour and related financial risks.
- The Maintenance Manager enables configuration control of the wind turbines in a project.
- Maintenance and failure data of large populations of wind turbines can be analysed very easy by both the service department and the R&D department. Analyses which are available in the system are among others the following:

ranking:	comparison of number of failures, downtimes, costs, failure causes per region, per park, per turbine, per main system or per component;
trend analyses:	investigation of the failure rate over a longer period of time and assessment of improvements, or effectiveness of the maintenance strategy
statistical analyses:	determination of RAMS data (reliability, availability, maintain-ability, and safety) from a large population for new turbine designs, e.g. MTTF (mean time to failure) and MTTR (meant time to repair) data;
component investigation:	comparison of the failure rates of various suppliers.

  The data can also be exported to MS Excel and Access if additional analyses are required.

Presently (January 2001) the Maintenance Manager is available as a stand-alone demonstration version for local use. All features are available in the demonstration version and have been tested and verified. In the next coming months, the system will be extended with automated data transfer and routines to synchronise the data between the central, regional and local systems. The default language is English; different languages are optional.

To distribute the Maintenance Manager for the wind energy market, ECN and B&R have signed a *distribution agreement*. In general it can be said that ECN provides the wind energy expertise whereas B&R provides the knowledge on maintenance technology and software development. To ensure that new customers (manufacturers, independent service companies, park owners) can work successfully with the Maintenance Manager, ECN and B&R will sell the license only together with the full implementation procedure. This includes the installation, personnel training, and assistance in the turbine definition and FMEA. Furthermore, ECN and B&R will organise evaluation visits on a regular basis after the Maintenance Manager is installed.

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1. INTRODUCTION

1.1 Why Maintenance Management?

Wind energy has become a professional branch of industry. Since the mid-nineties, the annual turnover of many European manufacturers has increased with 30 to 40 % per year. Now that wind turbines have exceeded the experimental stage, designers, manufacturers, owners, project developers, and suppliers are putting more emphasis on lowering the operational costs over the total lifetime in order to improve the economics of wind energy projects. Especially the economics of offshore wind parks are strongly dependent on the failure behaviour of the turbines. Small failures, although frequently appearing, will have minor impact on the availability of *onshore* wind turbines. However, in *offshore* windfarming, these small failures will lead to high unavailability and high operational costs due to the difficult accessibility and expensive repair costs.

Extensive analyses over a large number of turbines, e.g. [16], have shown that the annual costs for preventive and corrective maintenance for onshore turbines are about 2 % of the investment costs during the first 5 years. It is this value that is often used for the financial calculations in the early planning stage of wind energy projects. In [15] the costs for replaced components have been investigated also and based on expert opinions extrapolations have been made for the the costs for replacing failed components over twenty years lifetime. The extrapolation revealed that in this case the total costs over twenty years would 64 % of the investment costs. This corresponds to more than 3 % on an annual basis and it is likely that the annual maintenance costs will exceed the “2% value”.

Rough estimates of the maintenance costs for offshore wind parks indicate that these annually will be approximately 3 to 5 % of the investment costs. It should be noted that the total investment costs per kWh for offshore projects are much higher. As opposed to onshore turbines, these figures are not based on practical experiences. Keeping in mind that offshore wind turbines are not as mature as onshore turbines, the estimates are made with large uncertainties. The actual maintenance costs may even be an order of magnitude higher than the first estimates.

The above given considerations indicate that an adequate maintenance program in addition to a reliable design are of vital importance for the economics of future wind energy projects. In order develop such a maintenance program, it is necessary to have a clear understanding of the actual failure behaviour[1] of the turbines and equipment in a wind park. Based on the failure behaviour one can make underpinned decisions to optimise the initial maintenance schedule. One can vary the length of the maintenance intervals, choose for preventive instead of corrective maintenance, or apply condition-based maintenance. Furthermore, analysing actual failure data can be used for adjusting future designs aiming at improved reliability.

1.2 Managing RAMS Aspects

To develop an adequate maintenance program, it is necessary that the so-called RAMS aspects (Reliability, Availability, Maintainability and Safety) are considered in a structured manner in all phases of a wind turbine, viz.:

[1] *Failure behaviour* in this context means (1) the frequency of a failure and (2) the consequences of a failure in terms of repair costs, downtime, and revenue losses.

1. the design phase;
2. the prototype phase; and
3. the operational phase.

Since the early nineties, the unit ECN Wind Energy has carried out several projects to consider the RAMS aspects in the various phases.

Ad 1) In the design phase, the RAMS specifications for the entire turbine and its components should be defined, for instance the *mean time to failure* for electrical equipment. In the past, ECN Wind Energy has frequently applied methods for RAMS analyses to investigate the safety or reliability of the wind turbines, see [1], [2], [3], [4], and [5]. Experiences gained from these case studies have been used to select a suitable set of RAMS methods, which is presently being applied on a regular basis by several wind turbine designers. (See also final reports of the project "European Wind Turbine Standards", ref [6],[7],[8]).

Ad 2) Once a prototype of a turbine has been designed and built, extensive testing is necessary to collect data (mechanical loads, power output, natural frequencies etc.) to identify *teething troubles*, to propose design improvements, and product optimisation. ECN Wind Energy has a long-term experience in prototype testing and certifying new turbine designs.

Ad 3) Presently, ECN Wind Energy is developing new tools and methods that can be applied in the operational phase of a wind park. ECN is working on three highlights that will assist the manufacturers and park operators and owners in improving the reliability and reducing the maintenance costs, viz.

3.1 Automation of collecting, analysing, and reporting failure and maintenance data over a large turbine population to indicate weak spots in the design and to adjust the maintenance procedures if desired.

3.2 Developing methods to determine the health (or *condition*) of systems and components, e.g. to select wind turbines to be maintained with high priority or to change from preventive maintenance into condition based maintenance.

3.3 Developing algorithms for park control to maximise the power output and minimise the structural loads.

1.3 Collecting and Analysing Maintenance and Failure Data

This report discusses the results of a project entitled "*Development of a Maintenance Information System for Wind Turbines*". The project mainly dealt with item 3.1 mentioned above. The project was carried out between October 1999 and November 2000 by ECN, Baas & Roost Maintenance Consult BV (from now on called B&R) and Lagerwey the WindMaster (from now on called Lagerwey). A major part of the work was sponsored by the Dutch Organisation for Energy and Environment (Novem) in the Netherlands.

In this report, the following is being discussed:

- The background, objectives, and scope of the project (Chapter 2),
- A description of the main result of the project: a demonstration version of the maintenance information system, called the *Maintenance Manager* (Chapter 3). In this chapter, the structure of the Maintenance Manager is explained, the "wind energy specific" modules are discussed and illustrated by means of an example. Finally, the implications are being discussed when the Maintenance Manager is being installed at a service department.

2. THE PROJECT HIGHLIGHTS

2.1 Background

From the various safety and reliability studies, that ECN has conducted in the past [1], [2], [3], [4], and [5], it was learned that techniques for analysing the reliability or safety were available from other branches of industry and could be adopted by the wind industry on a short term. A set of techniques appropriate for analysing wind turbine safety and reliability such as FMECA (Failure Mode, Effects, and Criticality Analysis), FTA (Fault Tree Analysis) and ETA (Event Tree Analysis) has been documented in ref. [6], [7], and [8]. In the last decades, the analysis techniques can be bought as software packages for reasonable prices.

From the case studies performed by ECN, it was also learned that only very little data was available about failures, conducted maintenance, used spare parts, and related costs. This appeared to be a major bottleneck for further introduction of quantitative reliability analysis methods and defining the RAMS specifications. Although most of the data was collected by the maintenance technicians and reported to the service company and the manufacturer, it appeared to be very difficult and time consuming to extract for instance the following information:

- the top ten of most expensive failures,
- the top ten of the failures that contribute the most to the downtime,
- the mean time to failure for certain components,
- the effect of design modifications or adjusted maintenance procedures; does the number of failures decrease or increase?

It should be noted that this information is not only relevant for conducting quantitative RAMS analyses. The information clearly indicates the weak spots in the design or the maintenance procedures. In daily practice, the information will be used much more for the latter purpose than for conducting RAMS analysis.

Based on the conclusions of the safety and reliability studies and on available literature [12], [13], [14], ECN Wind Energy drew up some rough specifications to improve the data collection and analysis procedures for failure data of wind turbines [9], [10], and [11]. Among others, these specifications comprised the following.

- An FMECA format enables the best format to collect the data in a structured manner and to generate a data set that can be used for analyses afterwards. The format excludes the subjective opinion of the technicians to a large extent.
- To ensure that the maintenance technicians will collect the failure and maintenance data, it is important not to increase the workload for them; if possible even to reduce it.
- The information system has to be incorporated in the daily practices of the manufacturers and service departments. Double administrative work should be avoided.

Instead of developing a maintenance information from scratch, ECN looked for a partner with experience in the field of maintenance technology and software development. B&R[2] appeared to have knowledge on both. For their own consultant work, B&R uses the

[2] Baas & Roost Maintenance Consult is a specialist in the field of maintenance in many branches of industry and has 25 employees. Their main activities are performing risk and failure analyses, developing maintenance concepts and work instructions, optimising stock control, and improving the efficiencies of service departments, all with the objective to minimise the operational costs and meet the company's targets on production figures, safety, availability, etc.

Maintenance Manager, a maintenance information system that has been developed in-house. This system already contained many of the features initially specified by ECN in [9], [10], and [11]. It was decided to use the Maintenance Manager as a starting point and modify it to the specific needs of the wind turbine industry.

To ensure that the Maintenance Manager would result in a product that is useful for the target groups (manufacturers, service departments, and designers), a wind turbine manufacturer was involved in the project. Lagerwey served as a launching customer and provided practical feedback. Their LW 50/750 wind turbine was used as a case study throughout the entire project.

2.2 Objectives, Scope and Work

The objective of the project "*Development of a Maintenance Information System for Wind Turbines*" was to modify the existing Maintenance Manager to the needs of the wind energy community and to demonstrate it by a case study of the LW 50/750 wind turbine.

In the first phase of the project, specifications were drawn up for the maintenance information system after discussions with several wind turbine manufacturers and service companies. The specifications are reported extensively in [17].

Secondly, the specifications were programmed and the existing Maintenance Manager of B&R was modified into a wind energy version. A CD-ROM with a demonstration version is available on request. The various functionalities and new options in the Maintenance Manager were tested continuously throughout the project by means of the LW 50/750 turbine. During the execution of the project, Lagerwey monitored the progress and relevant feedback was received from the design and service departments. Within the constraints of the project, not all specifications could be taken into account. Especially the automated synchronisation between databases at various locations could not be achieved. This work has been postponed to a follow-up project (see also Chapter 5 for future developments).

As is already stated in the introduction and in various literature sources, maintenance procedures can be improved by using the actual failure data. To investigate and demonstrate whether this philosophy is also applicable for wind turbines, a third task was carried out by B&R. Three wind turbine components (a pitch bearing with an inner gear ring, a pitch motor, and a bolt connection) with their initial maintenance programs have been selected. The initial maintenance program for these components consisted among others of inspection each half-year, functionality testing each half-year, lubrication of bearings and pre-tensioning of bolts each year, etc. B&R has made several Monte Carlo simulations with their *Maintenance Optimizer*. Based on the results, B&R proposed an improved maintenance program with less cost and less failures than the initial program. The results are reported in [18] and available on request.

3. THE MAINTENANCE MANAGER

3.1 Specifications

The *Maintenance Manager*, is a database system to collect, analyse, and feedback failure and maintenance data of large series of wind turbines in a simple and structured manner. It has been designed according to the specifications in [17] which are summarised briefly below.

- Reporting the failure data should require minimum effort from the maintenance technicians.
- Reporting should be done in a structured manner, independent from the language or the technician, in order to facilitate analysis of the collected failure and maintenance data.
- The implementation of the Maintenance Manager should not lead to an extra database system where redundant information has to be filled in. It should be complementary to existing databases for e.g. stock control, financial administration, or the monitoring system, while data from the Maintenance Manager can be transferred easily to other systems if required.
- The Maintenance Manager should be adjusted to the daily practices and to the level of education of the users.
- The management team, the R&D department, the service departments, or the quality department must be able to perform at least the following analyses on the collected data (see also Section 3.3.3):
  - ranking (number of failures, downtime, costs, etc.);
  - trend analysis;
  - statistical analyses;
  - detailed component investigation.
- The Maintenance Manager should assist in configuration control.
- The Maintenance Manager should consider to the specific wind energy aspects like geographical spread and different external conditions.

The Maintenance Manager for wind energy applications in fact consists of four main modules.

1. A *definition module* to define wind parks with their geographical position, turbines with their structural breakdown and their failure modes, and spare parts.
2. A *maintenance schedule module* to plan the initial maintenance program and to control the day-to-day work planning.
3. A *logbook module* to record failures, maintenance that has been carried out and related costs.
4. An *analysis part* to analyse the reported failures and make reports for interested parties.

The modules will be discussed one by one in Section 3.3.

3.2 General Description

If the Maintenance Manager is installed, a central, regional, and local version of the database system can be distinguished.

The manufacturer controls the *central database* in which the turbine is defined, together with the initial maintenance plan. Furthermore, the manufacturer is able to perform analyses on all turbines from all maintenance departments.

The maintenance departments and the external service companies control the *regional databases*. In the regional database, the failure data reported by the technicians are collected. The maintenance departments are able perform analyses on all wind turbines in their regions. The maintenance departments plan the day-to-day maintenance work and if necessary, they modify the maintenance program.

The technicians control the *local databases* on their laptops, The local database is mainly intended to record the failure and maintenance data. They can perform only few analyses. A strong benefit of the Maintenance Manager for the technicians is the configuration control. The technicians know exactly which components from which suppliers they are in the turbines they are working on.

The Maintenance Manager is designed in such a way that a wind turbine manufacturer provides the maintenance departments (sometimes located in different countries) and their technicians with the relevant turbine data like design information, information on spare parts, and maintenance procedures. The technicians and maintenance departments on the other hand record maintenance and failure data that have to be analysed by the maintenance departments and/or by the manufacturer. The usual data flow between the various departments and the role of the *Maintenance Manager* is sketched in Fig. 3.1.

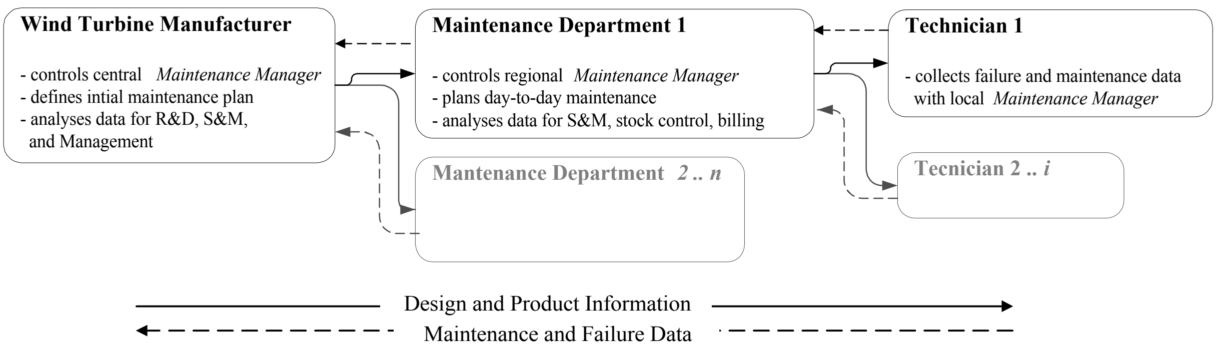


Fig. 3.1: *The data flow between the various departments*

3.3 Program Structure

As is stated already in the previous section, the Maintenance Manager consists of four main modules and they will be discussed one by one.

3.3.1 Definition

In order to ensure that the users of the Maintenance Manager can perform the relevant analyses and to ensure configuration control, the data shall be collected in a structured format. This means that the technicians have to fill in the data in accordance with a strict format instead of using a free format.

In the definition module, it is possible to define all relevant data of a turbine, among others: in which park the turbine is placed, at what date it has been taken in operation, the main systems, the supplier of a main system, and the parts list. By doing so, configuration control is possible and the technicians can easily retrieve what component of what supplier is placed in which turbine. In the definition module, at least the following turbine data shall be defined.

1. Region
    2. Wind Park
        3. Wind Turbine
            4. Main Systems (or: Building Blocks)
                5. Components
                    6. Sub- Components

In Fig. 3.2 a screen of the definition module is presented and the tabs correspond to the 6 levels above. Relevant for the configuration control is that all components have a unique position in the turbine, identified with a TAG number. The Maintenance Manager offers the possibility to attach additional information to the main components, e.g. the supplier's name and the serial number.

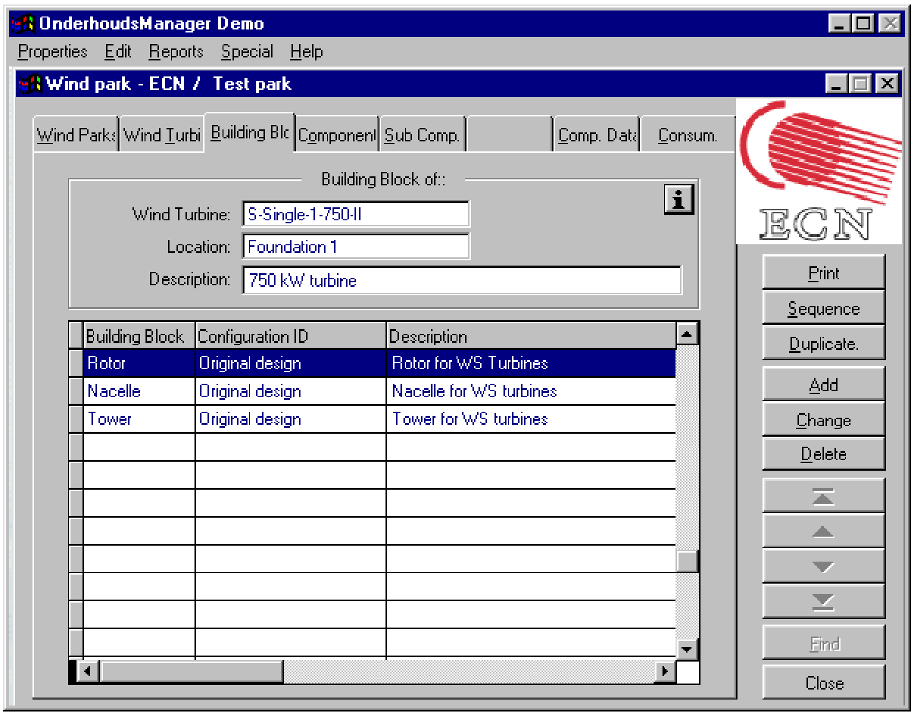


Fig. 3.2: *A screen of the definition module*

In the Maintenance Manager, the fifth level is the tab "Components". This is the level at which items are being serviced. It is also the level at which data should be collected for analyses by the R&D or S&M departments. To make sure that all-relevant background information of a failure is collected, a Failure Mode and Effects Analyses (FMEA) has to be performed. For each component, the possible failure modes and failure causes should be defined. In Fig. 3.3, the FMEA for a yaw brake is shown.

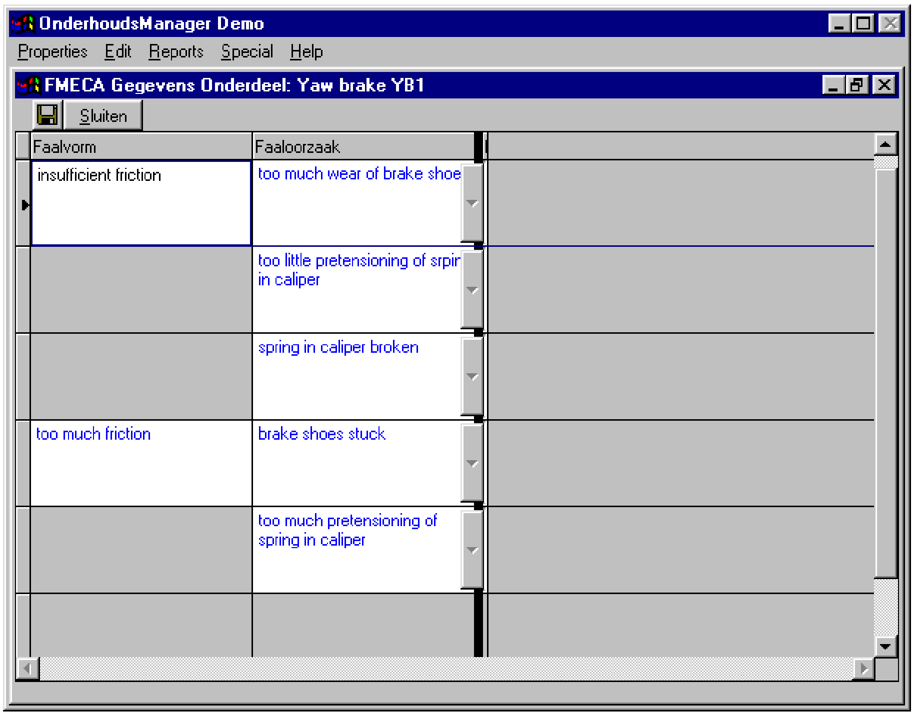


Fig. 3.3: *Failure modes and causes of yaw brake*

One might think that performing an FMEA for the entire turbine is very time consuming. However, the Maintenance Manager uses special FMEA *libraries* that can be easily linked to the components. ECN has already built an extensive FMEA library for components that are frequently used in wind turbines like blades, gearboxes, relays, pitch bearings, pitch motors, towers, generators, etc.

Once the first of a large series of wind turbines has been defined, a complete wind park can easily be defined by duplicating the turbine, including all its components and FMEA data. Only very specific information has to be added, e.g. the serial number of a blade or the name of a gearbox manufacturer when it differs from the preferred supplier.

3.3.2 Maintenance Schedule

All components to be serviced, have their individual maintenance program. Usually such a maintenance program consists of preventive maintenance actions (lubrication, checking pre-tensioning of bolt connections, functional tests, etc) with a recurrence interval of half a year or one year. In Fig. 3.5, it is shown how the maintenance plan for the yaw brake is defined. The tab “Informatie” is intended to give extra information on the maintenance action. For instance a link can be made to the relevant paragraphs in the maintenance manual, reference can be made to the drawings, or a detailed description can be given on the procedures. Furthermore it is possible to report trends in wear. It is possible to report the measured thickness of the brake shoes and determine the wear as a function of time, or to report the results of oil analysis.

In Fig. 3.6, an example is given of how maintenance work is planned and controlled with the Maintenance Manager and how technicians report what work they have been carried out. The screen for controlling the maintenance work in fact works as a checklist.

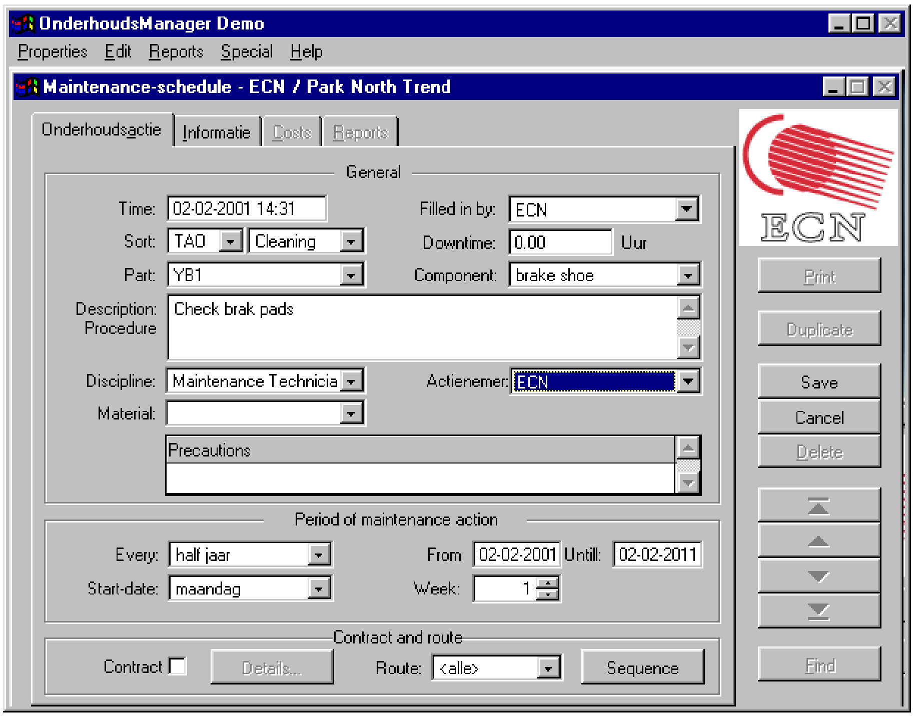


Fig. 3.5: *Screen for defining the maintenance program of the individual components*

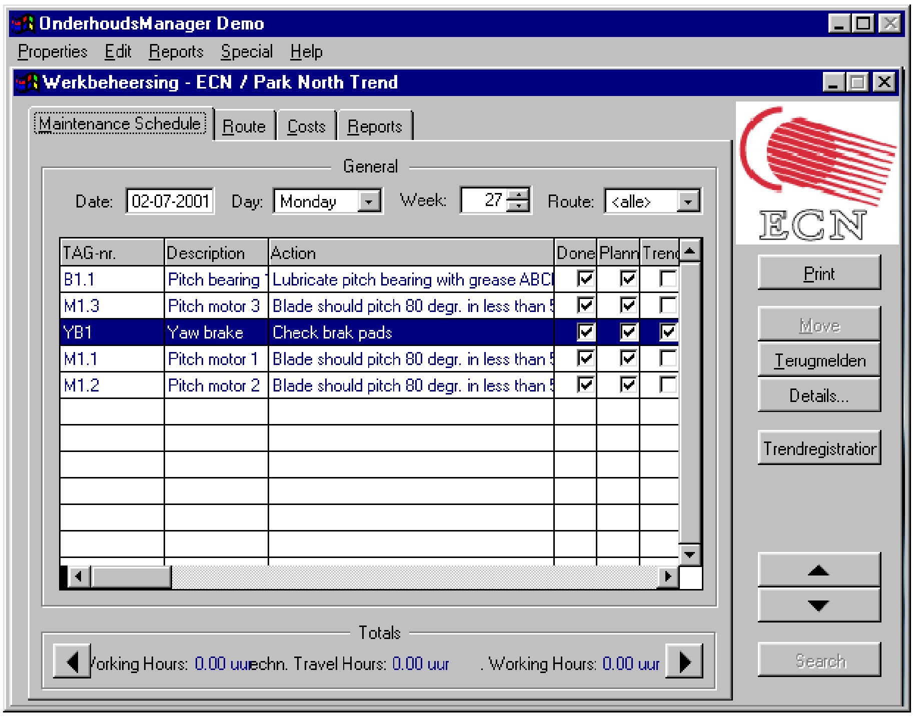


Fig. 3.6: *Screen for planning and controlling preventive maintenance and report trends*

3.3.3 Logbook

The logbook module in fact consists of four parts that correspond to the tab's in Fig. 3.7: the *Log* part, the *Failure data* part, the *Specification* part, and the *Reports* part.

Tab: Log

The tab *Log* is being used to report the administrative information as soon as a failure has been reported to a service centre or a maintenance technician. In the daily practice of a service company, a turbine failure is usually being detected through:

- an alarm from the turbine monitoring system which automatically calls the service centre or the maintenance technician;
- an observation from an operator or passer-by who informs the service centre;
- an observation from a maintenance technician who is visiting the turbine to carry out either regular maintenance or a design modification.

A unique and wind energy specific feature of the Maintenance Manager is that the type of failure detection can be reported by means of a combo box. By doing so, the quality of the detection methods can be assessed. If for instance a failure is detected most of the time by inspection, one can consider adding an extra alarm to the turbine.

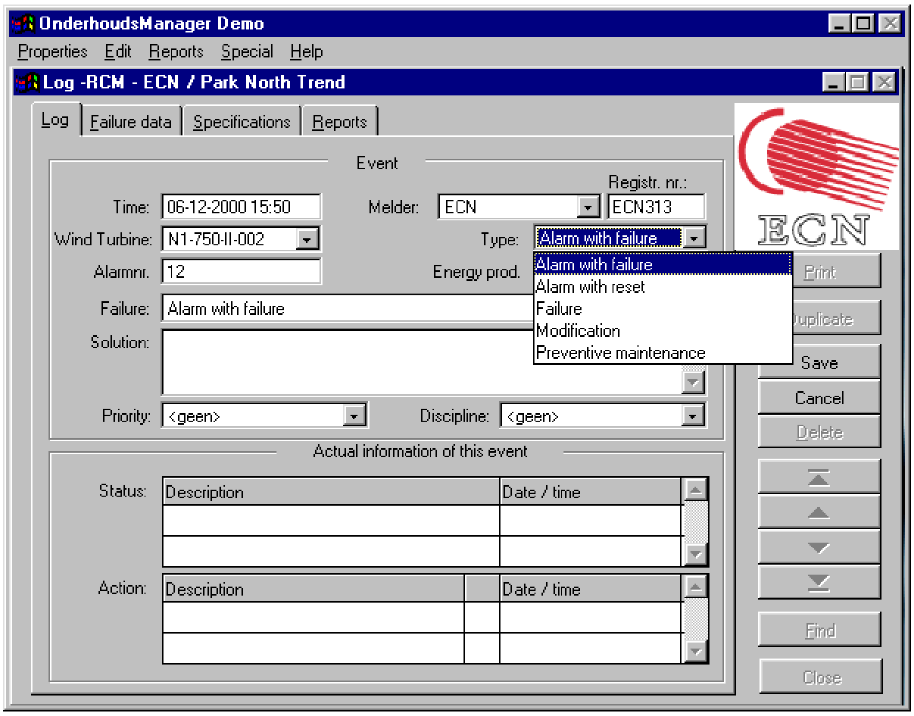


Fig. 3.7: *The tab "Log" in which an "alarm with a failure" is being reported*

Tab: Failure data

The technician who carries out the maintenance will usually fill in the tab Failure data. The tab is intended to report relevant background information on a failure. The time at which the failure was detected, at which the repair was started, and at which the turbine was restarted, enables detailed downtime analysis afterwards. By means of a combo box the technician can fill in the type of work he has carried out, viz. reset, repair, replacement, or others.

The FMEA data from the definition module is being used to report the failure modes and failure causes. This provides a structured format for the failure registration and limits the time needed to report the failure. The technician has to double click on the FMEA window to report that the yaw motor has insufficient friction because the spring in a calliper was broken, see Fig. 3.8. The technician found out that it had to do with the root cause "incorrect assembly" which is listed in a combo box.

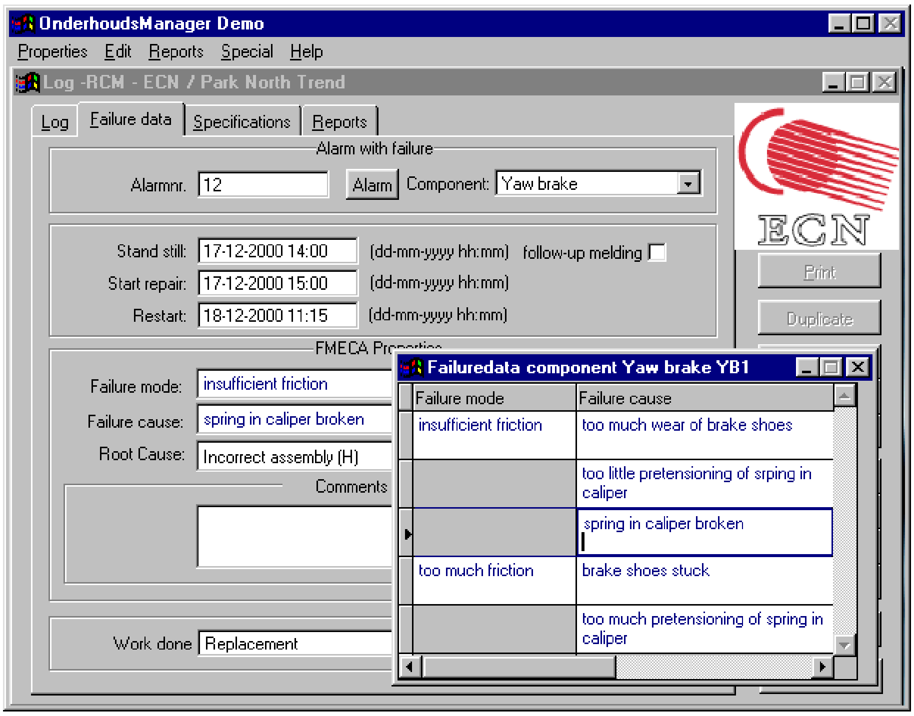


Fig. 3.8: *Reporting a component failure with its failure mode and cause in the tab "Failure data"*

Tab Specifications

The tab *Specifications*, is designed to fill in the costs that are related to a failure such as materials, labour costs, consumables and costs of equipment, see Fig. 3.9. This information is being used for cost analyses. Moreover, the data will be used for the financial administration of the manufacturer, farm operator, etc.

Tab Reports

The tab *Reports* is not operational yet but will be designed to the specific requirements of the customers. The Maintenance Manager can produce reports for e.g. the owner of the turbine to inform him about the conducted maintenance work. These reports will be used instead of the traditional worksheets with the carbon copies. On request, reports can also be made for the financial administration or for stock control.

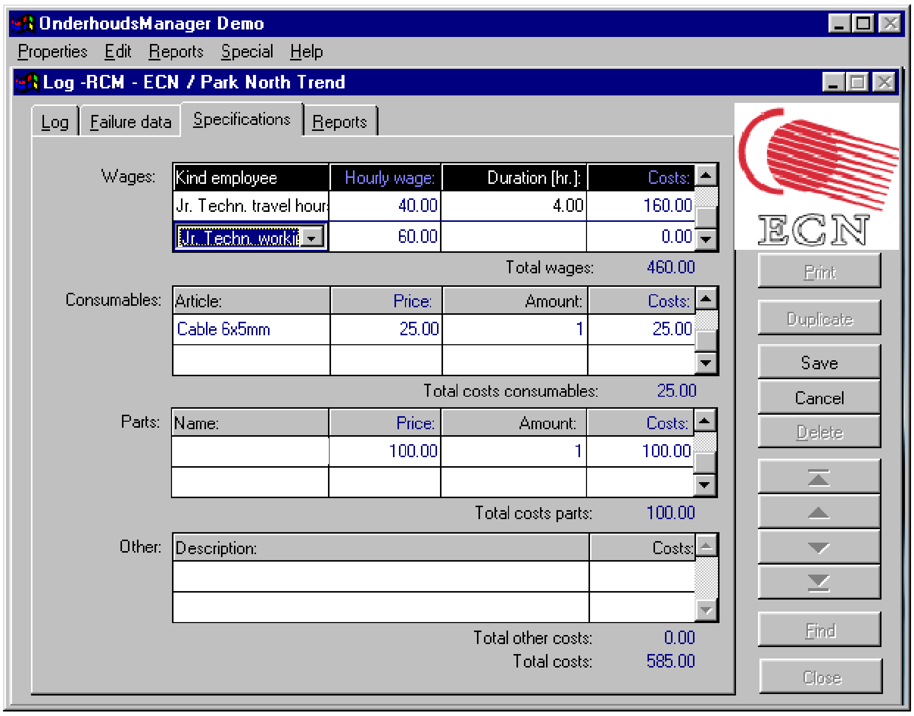


Fig. 3.9: *Tab "Specifications" to report the costs*

3.3.4 Analysis

With the analysis module the collected data can be analysed, for instance to identify critical items in the design or in the maintenance procedures. To demonstrate the capabilities of the Maintenance Manager, a limited number of representative examples is given below.[3]

> Example: Let us assume that a manufacturer has sold turbines of one type to three different parks:
>
> - Park North (10 turbines)
> - Park South (25 turbines)
> - Single 1 (1 turbine)
>
> Park South and the single turbine are being maintained by an external service centre which is located close to park South. Park North is being maintained by the service department of the manufacturer.

[3] More options for data analysis are available at the moment in the Maintenance Manager. In case additional analyses are required which are standard not available in the Maintenance Manager, it is always possible to export the data to the data base Access or the spread sheet Excel for further analysis.

3.3.4.1 Ranking

With the option *Ranking,* one can compare for instance the maintenance costs, the number of failures and the downtimes. The ranking can be performed on different levels, e.g. one can rank the number of failures per region, per park, or per wind turbine, or one can rank on the component level to find out which components fails most frequently.

<u>Example:</u> The manufacturer compares the maintenance costs over the last three years between the various parks. He concludes that the maintenance costs for Park South, maintained by an external company, are about 5 times lower than for park North, maintained by himself, see Fig. 3.11. Ranking the number of failures (Fig. 3.12) reveals that the higher maintenance costs are partly caused by a higher number of failures. It is assumed that the quality of the components in Park South is better. However, it does not explain the whole difference. A downtime analysis (Fig. 3.11) reveals that the downtime for Park North is very high. Apart from the quality of the components, it is assumed that the maintenance procedures of Park North are not adequate and too expensive. Namely, both the logistics time and the actual repair time are a factor of 10 higher.

Further analysis of the failure and maintenance data is required to verify the assumptions on the quality of the components and on the maintenance procedures. In this example, the manufacturer ranks the failed components of all three wind parks and finds out that the yaw brake is the most vulnerable component.

Please note that the values on the y-axis are normalised to [per turbine] to make the results independent from the size of the park and to enable a fair comparison between the parks. The time periods over which the analyses have been performed are the first three years of operation of the turbines. It is also possible to select all data or one or more calendar years.

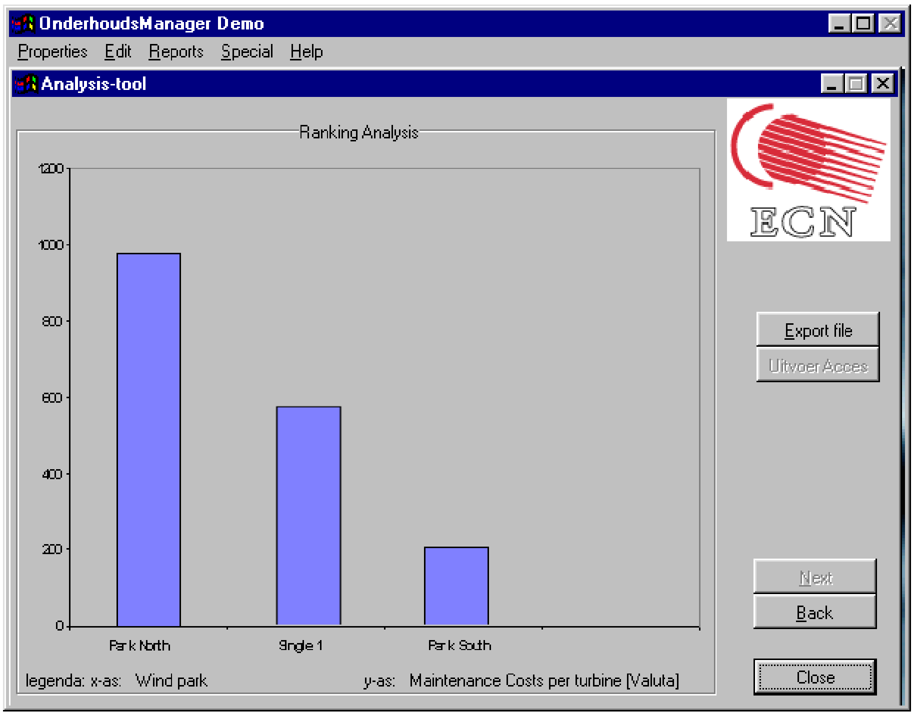


Fig. 3.11: *Repair costs per turbine for all three wind parks*

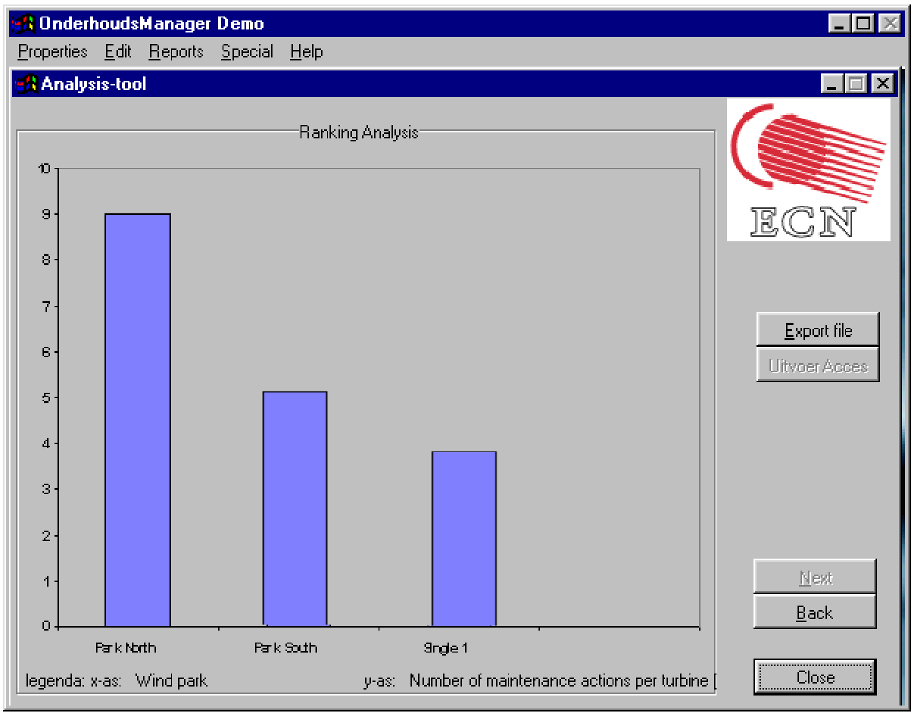


Fig. 3.12: *Number of maintenance actions per turbine (= number of failures) for all three wind parks*

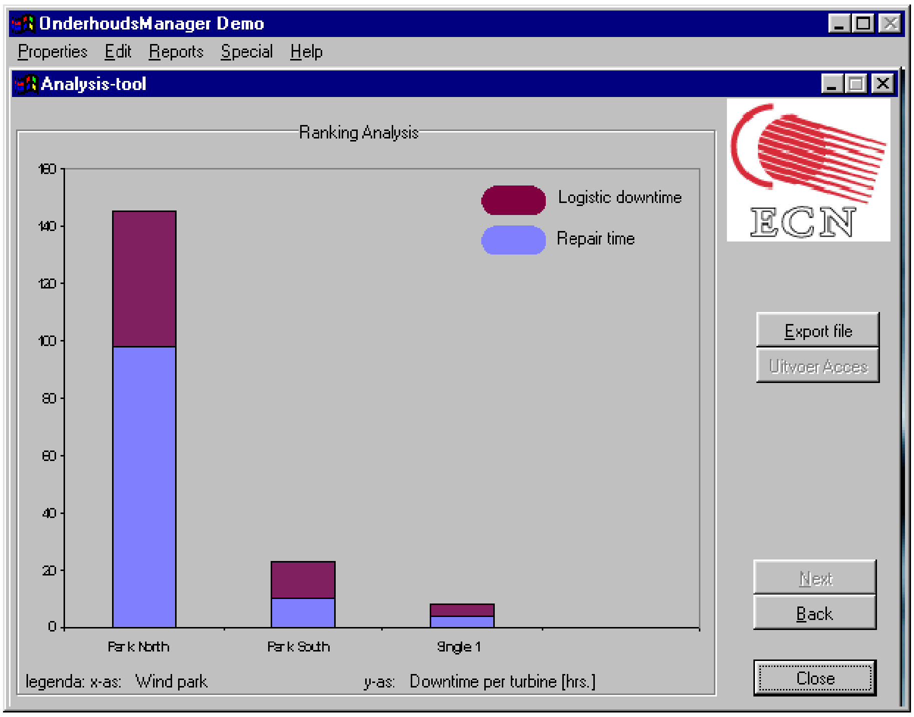


Fig. 3.13: *Logistics downtime and repair time per turbine for all three wind parks*

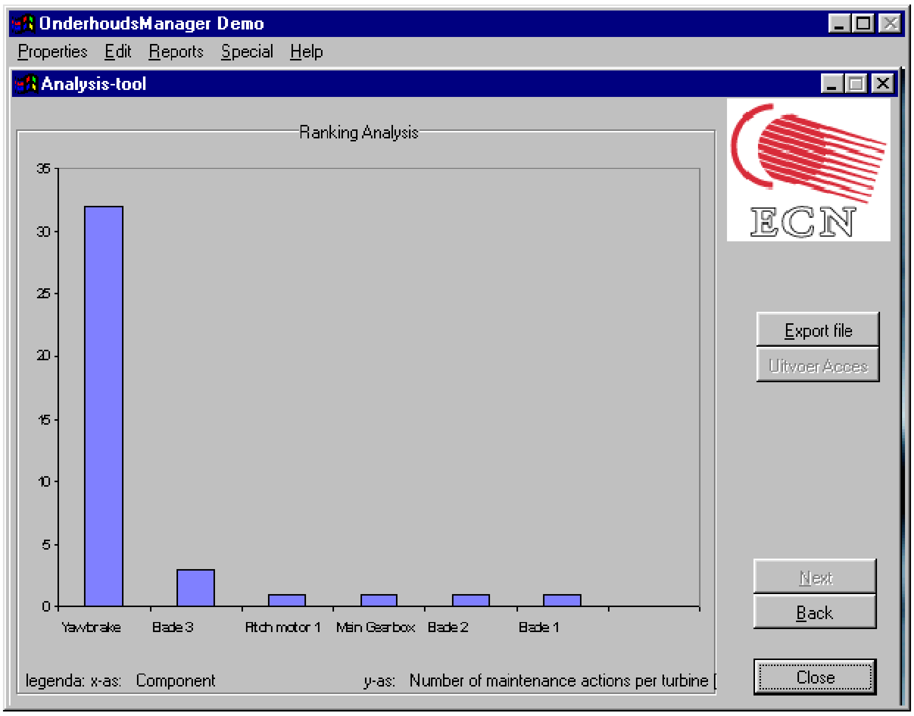


Fig. 3.14: *The yaw brake has failed most frequently*

3.3.4.2 Component Data

With the analysis option *Component Data* in the Maintenance Manager, can investigate in detail the failure behaviour of a certain component. One can compare for instance the number failures for certain suppliers, one can rank what kind of maintenance work has been done (replacement, cleaning, etc.), or one can look for the dominant failure modes.

> Example: The manufacturer finds out that the yaw brakes of *Supplier B* have much more failures than those of *Supplier A*. (See Fig. 3.15). The assumption that the component quality of Park South is better is correct. The yaw brakes of Supplier B have only been used in Park North. Park South was equipped with yaw brakes from Supplier A.
>
> Perhaps it is possible that with some small modifications, the R&D department can improve the design of supplier B. Therefore, the manufacturer needs to know what the most dominating failure causes are. As can be seen in Fig. 3.16, a broken spring calliper caused 12 out of 32 failures.

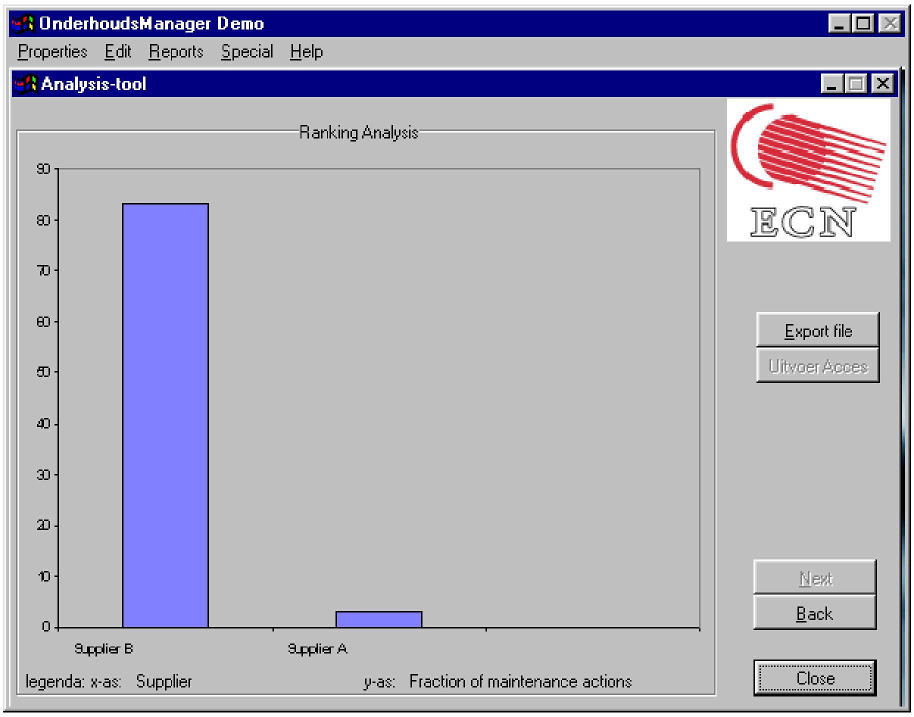


Fig. 3.15: *More than 80 % of the failed yaw brakes were supplied by Supplier B*

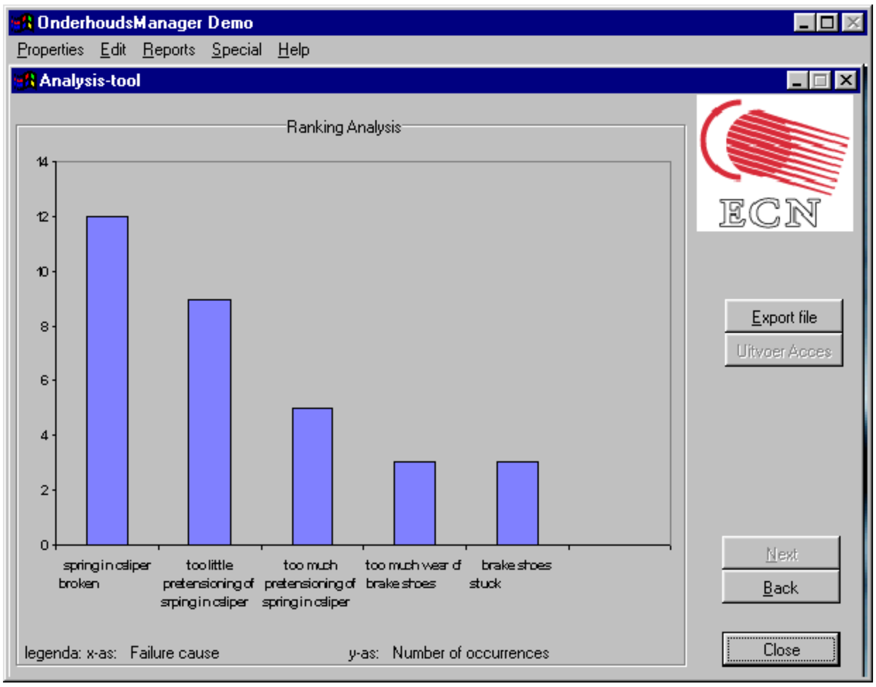


Fig. 3.16: *12 out of 32 failures were caused by a broken spring calliper*

3.3.4.3 Trend Analysis

The option *Trend Analysis* of the Maintenance Manager offers the possibility to determine the probability that a component or system will fail as a function of the time it is in operation. Two different types of analysis are available, viz. the *failure rate* and the *failure intensity*.

The *failure rate* can be applied for components, which are replaced after a failure. An increasing failure rate might indicate that the components are being subject to ageing and a suitable time period for preventive maintenance can be chosen.

The *failure intensity* can be applied for systems that are being repaired and continue operation after repair. The failure intensity can give information about the effectiveness of the current maintenance procedures.

<u>Example:</u> The trend analysis of the yaw brakes results in the failure intensity curve as shown in Fig. 3.17. Most of the failures of the yaw brakes in Park North occur at the beginning of their lifetime. The failure intensity remains more or less constant after the yaw brakes are in operation for about one year. This indicates that the applied maintenance concept is now adequate.

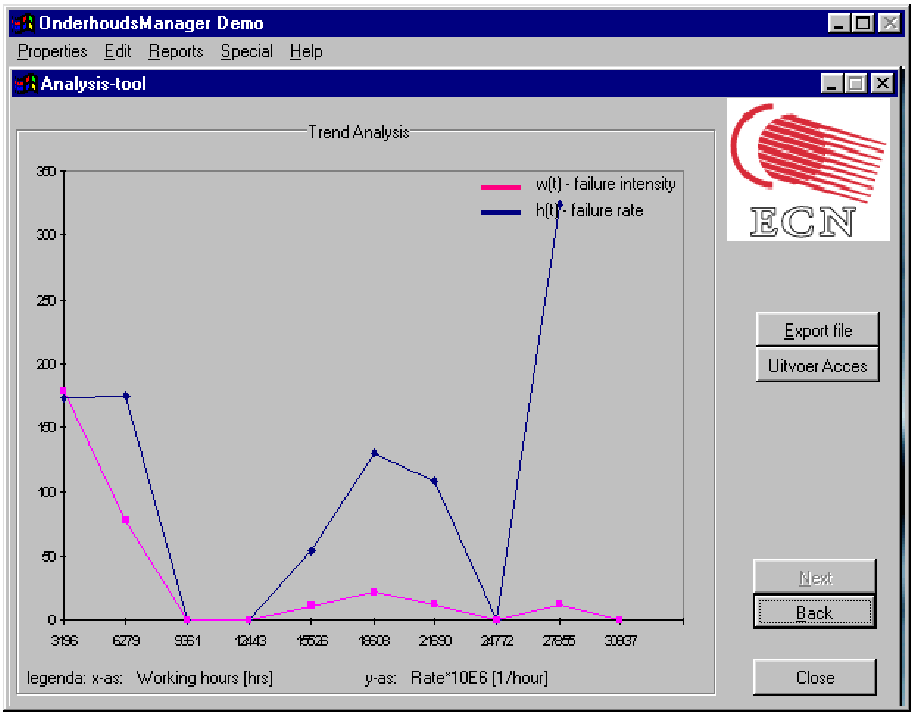


Fig. 3.17 *Failure intensity of the yaw brake (the curve "failure rate" applies to other types of components)*

3.3.4.4 Statistical Analysis

The option *Statistical Analysis* offers the R&D department the possibility to derive statistical data from the large population of turbines, systems and components. E.g. If a wind turbine is equipped with three identical pitch motors, the Maintenance Manager determines easily the Mean Time Between Failure (MTTF) values. The Maintenance Manager takes into account the number of turbines, the number of pitch motors, the number of failures, the downtimes, etc. The MTTF values can be used for new designs and to verify if the actual failure data meet the initial RAMS specifications.

<u>Example:</u> The manufacturer is now developing a new turbine. It is an offshore version of the turbines that are operating in the parks *Park North*, *Park South* and *Park Single 1*. Since minimisation of the number of failures and maintenance effort is an important design driver, the failure rate of the yaw brakes has to meet the RAMS target. The R&D department has the impression that the yaw brakes of Supplier A are suitable for the new turbine. A statistical analysis is performed to derive the MTTF values, see Fig. 3.18.

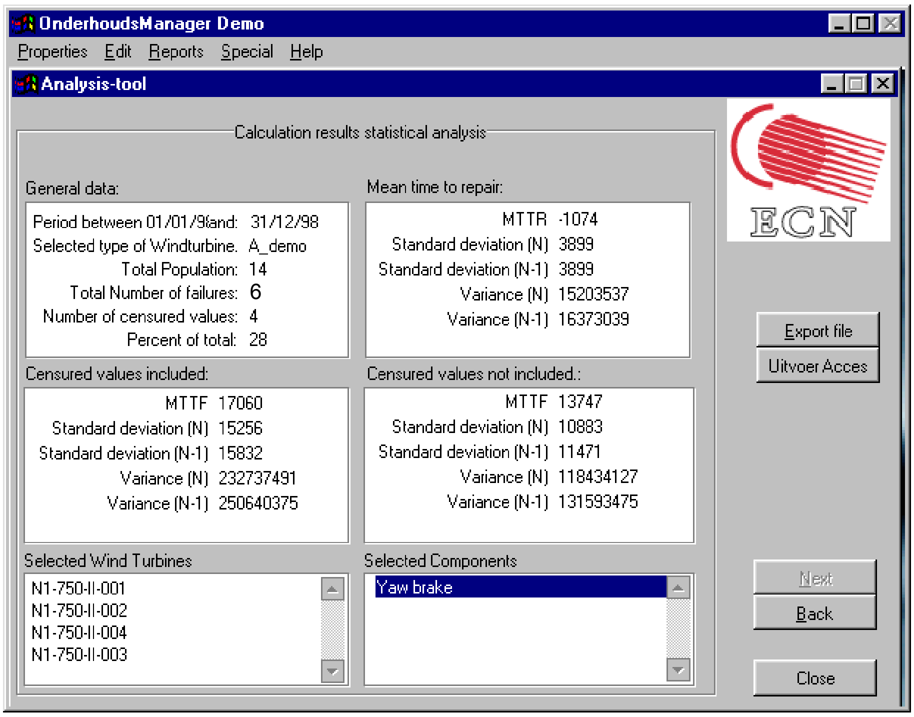


Fig. 3.18: *Statistical analysis of the yaw brake*

4. STATUS AND IMPLEMENTATION

4.1 Status and Future Developments

Within the project "*Development of a Maintenance Information System for Wind Turbines*" the existing Maintenance Manager of Baas & Roost Maintenance Consult has been adjusted to collect and analyse maintenance and failure data of a large population of wind turbines. The existing definition module to define parks and turbines and the existing logbook module were adjusted to the specific needs of the wind energy community. The analysis module was developed from scratch. All available options have been tested, verified, and documented. The demonstration version as it is now can be used to collect and analyse the data of a few wind parks. The Maintenance Manager works satisfactory as a stand alone version and manual data transfer from and to laptops is possible.

At the end of the project, the demonstration version of the Maintenance Manager has been discussed with the intended users. Presently, the system is being tested and experiences from the users are being collected to improve the system. In the next coming months, the following major improvements and adjustments will be put through.

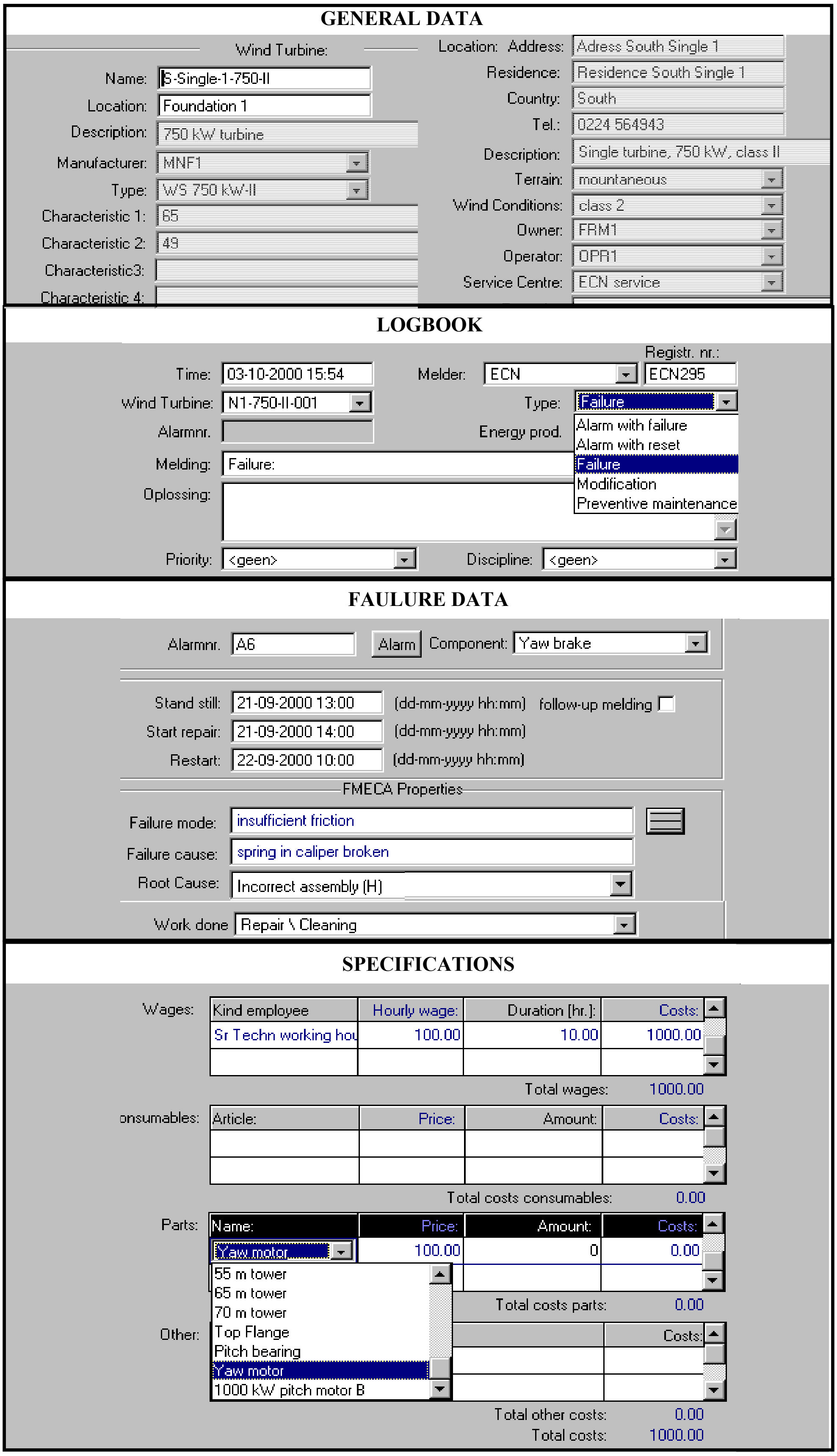
- The system will be modified to enable automated data transfer and routines to synchronise the data between the central, regional and local systems.
- The user friendliness of especially the "logbook module" and the FMEA will be improved. It will be adjusted to the specific needs of future clients to reduce the number of mouse clicks for failure registration. The lay out will be similar to that of the conventional work sheets. An example is given in Fig. 4.1.
- The maintenance schedule module works satisfactory for one plant. To plan the daily work for an entire service centre, the Maintenance Manager needs to be adjusted. This will only be done if potential users show sufficient interest in this module.

4.2 Integration in the Daily Practice

By the end of 2001, all above mentioned changes and fine-tuning will be ready. In this section it is sketched how the Maintenance Manager should be integrated into the daily practice of a manufacturer or a service company.

In most service departments one or more complementary information systems are used for:
- financial administration,
- configuration control,
- stock and spare parts control, and
- planning the day-to-day maintenance work for the technicians.

Furthermore, the service departments might have access to some kind wind turbine monitoring system, providing access to information like: the status of the turbines, alarms, energy production, etc. The manufacturer in addition also has a database system to manage the design documentation and the parts lists during the design. Once the turbine (or a series of identical turbines) is being commissioned, the parts lists and the design documentation are handed over to the service department. From that time on, the configuration control is under the responsibility of the service department.



GENERAL DATA

Wind Turbine:

Name: S-Single-1-750-II
Location: Foundation 1
Description: 750 kW turbine
Manufacturer: MNF1
Type: WS 750 kW-II
Characteristic 1: 65
Characteristic 2: 49
Characteristic3:
Characteristic 4:

Location: Address: Adress South Single 1
Residence: Residence South Single 1
Country: South
Tel.: 0224 564943
Description: Single turbine, 750 kW, class II
Terrain: mountaneous
Wind Conditions: class 2
Owner: FRM1
Operator: OPR1
Service Centre: ECN service

LOGBOOK

Time: 03-10-2000 15:54
Melder: ECN
Registr. nr.: ECN295
Wind Turbine: N1-750-II-001
Type: Failure
Alarmnr.:
Energy prod.
Alarm with failure
Alarm with reset
Failure
Modification
Preventive maintenance
Melding: Failure:
Oplossing:
Priority: <geen>
Discipline: <geen>

FAULURE DATA

Alarmnr. A6 Alarm Component: Yaw brake

Stand still: 21-09-2000 13:00 (dd-mm-yyyy hh:mm) follow-up melding
Start repair: 21-09-2000 14:00 (dd-mm-yyyy hh:mm)
Restart: 22-09-2000 10:00 (dd-mm-yyyy hh:mm)

FMECA Properties

Failure mode: insufficient friction
Failure cause: spring in caliper broken
Root Cause: Incorrect assembly (H)
Work done Repair \ Cleaning

SPECIFICATIONS

Wages:

Kind employee	Hourly wage:	Duration [hr.]:	Costs:
Sr Techn working hou	100.00	10.00	1000.00

Total wages: 1000.00

onsumables:

Article:	Price:	Amount:	Costs:

Total costs consumables: 0.00

Parts:

Name:	Price:	Amount:	Costs:
Yaw motor	100.00	0	0.00

55 m tower
65 m tower
70 m tower
Top Flange
Pitch bearing
Yaw motor
1000 kW pitch motor B

Total costs parts: 0.00

Other: Costs:

Total other costs: 0.00
Total costs: 1000.00

Fig. 4.1: *Example of a user friendly input sheet*

Usually, the service department generates work instructions for its technicians, e.g. to carry out regular maintenance or repair a failure. The technicians fill out work sheets that are being collected for the financial administration (invoicing to the turbine owner, salary administration), for stock control, or for adjusting the daily work planning.

Below it will be explained to what extent the Maintenance Manager can replace the existing information systems, and where it is complementary. The additional information that can be derived as compared to the existing situation will be outlined.

- With the Maintenance Manager it is possible to plan the day-to-day maintenance work of a service department. Work instructions can be generated for the technicians. They can be based on the initial preventive maintenance plan or on proposed design modifications. After some client specific adjustments are made to the maintenance schedule module, the Maintenance Manager can replace the planning software.
- With the Maintenance Manager, technicians do no longer fill in the paper work sheets. They easily report the work that has been carried out on a laptop. If preventive maintenance work is finished, the technician simply clicks the " ✔" symbol at the laptop, see Fig. 3.14. A corrective maintenance action should be reported in the *Logbook*, see Section 3.3.3. The data filled in by the technicians on their laptops can automatically be transported to the computer at the service department for further analyses.
- The Maintenance Manager cannot replace the systems for financial administration. However, the Maintenance Manager can generate "digital reports" which serve as input for financial administration and stock control. A sheet as given in Fig 4.1contains all relevant information. The wind turbine monitoring system informs the service departments about the status of a turbine, the energy production, and the alarms. The actual consequences of an alarm such as the repair and labour costs are not being reported in the monitoring system. (The same holds for malfunctions found during regular maintenance.). As soon as manual intervention is required after an alarm, the information should be filled in in the Maintenance Manager. Automatic resets are not being reported.
- The parts lists generated by the R&D department can be imported into the Maintenance Manager. The FMEA data in the libraries can be linked to the parts lists.
- A strong benefit of the Maintenance Manager is the possibility for configuration control during the lifetime. In the definition module, the turbine is being defined in great detail and all components have a unique identification. By adding the supplier's name and, the serial numbers to the main components it is always known what components are in the turbine, for how long, and from what supplier.
- The strongest benefit of the Maintenance Manager however is the data analysis part to feedback failure and maintenance data for further optimisation.

4.3 Implementing the Maintenance Manager

In general, the Maintenance Manager can be implemented in two situations:

Situation 1:	At the offices of a manufacturer and his service department.
Situation 2:	At a service company that maintains turbines that have been placed by a manufacturer

Situation 1: *Manufacturer*

To obtain an impression of the work and effort that is needed to fully install the Maintenance Manager at one desktop computer of the manufacturer, one desktop computer of the service department and on the laptops of the technicians, the implementation scenario is given below.

1. The Maintenance Manager has to be installed at the desktop computers of the manufacturer and the service department and on the laptop computers of the technicians. This includes:
   - tailor made synchronisation routines and procedures for data transmission (e.g importing parts lists into the Maintenance Manager and exporting data for financial administration),
   - preparation of special reports and sheets, e.g. for invoicing to customers.

   This will take about six to ten days for ECN and B&R, depending on the specific requirements of the customer and on the hard- and software that is already available at the company.
2. ECN and B&R need two to five days to train the personnel, depending on the number of people to be trained.
3. The wind turbine designs under consideration have to be defined, including the FMEA data. If the digital parts lists are available, the FMEA data from the libraries can be linked to the parts lists. An experienced reliability analyst uses approximately ten days to define a new turbine design in the Maintenance Manager, assuming that the required data are available. A second design can be done in half the time.
4. From now on, new wind turbines and new wind parks can be defined by copying the initial turbine design and modifying the serial numbers and suppliers' names if necessary. Employees from the R&D or service departments can define a new wind turbine with FMEA data in a few minutes and define a new park in approximately half a day.

Situation 2: *Service Company*

Once the manufacturer is working with the Maintenance Manager and turbines are sold to a new region with a new service company, the Maintenance Manager only has to be installed at the new service company and on the laptops. Personnel need to be trained. This is a limited amount of work, say five to eight days for ECN and B&R. The turbines with the parts lists and FMEA data have already been defined.

4.4 More Information

To distribute the Maintenance Manager for the wind energy market, ECN and B&R have signed a distribution agreement. In general it can be said that ECN provides the wind energy expertise whereas B&R provides the knowledge on maintenance technology and software development.

A standard license for the Maintenance Manager will comprise one version at the desktop PC and five versions on the laptops of the technicians. Such a license costs 4.600 Euro (tariff in 2001) and is valid for three years. An annual service contract costs 20% of the licence price. If the Maintenance Manager has to be installed on more than five laptops, this will be done for reduced prices.

To ensure that new customers can work successfully with the Maintenance Manager, ECN and B&R will sell the license only together with the full implementation procedure as sketched in Section 3.5.1. This includes the installation, personnel training, and assistance in the turbine definition and FMEA. Furthermore, ECN and B&R will organise evaluation visits on a regular basis after the Maintenance Manager is installed.

If you are interested or have comments or suggestions, please contact:

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ECN project number **Order number**	7.4087 224.321-9957
Programme(s)	TWIN

Abstract

With the increasing maturity of wind energy, designers, manufacturers and suppliers are putting more emphasis on lowering the operational costs over the total lifetime in order to improve the economics of wind energy projects. Especially the economics of offshore wind parks will become sensitive to the failure behaviour of the turbines. An adequate maintenance program in addition to a reliable design is very crucial for the economics of future wind energy projects. To develop such a maintenance program, it is necessary to have a clear understanding of the actual failure behaviour of the turbines and equipment in a wind park.

The Netherlands Energy Research Foundation ECN and Baas & Roost Maintenance Consult BV have carried out a project entitled "Development of a Maintenance Information System for Wind Turbines" in which a system has been developed, called the "Maintenance Managers", to collect and analyse failure and maintenance data of large wind turbine populations.

This report briefly discusses the necessity of controlling maintenance for future large wind energy projects and the role of maintenance and failure data. Furthermore, the report contains a description of the project, including its background, objectives, and scope. In this report, most emphasis is put on the results of the project, viz. the demonstration version of the Maintenance Manager.

The Maintenance Manager was programmed based on specifications drawn up in close co-operation with Lagerwey the WindMaster BV and other wind turbine manufacturers. In addition to the most commonly used maintenance management system for planning day-to-day maintenance work, this system is equipped with some unique features, viz. an FMECA module, and a strong analysis tool for ranking, trend analysis, statistical analysis, and detailed component investigation. These unique features offer wind turbine manufacturers the possibility to obtain maximal feedback from their failure and maintenance data with minimum effort.

Key words Wind energy, Reliability, Maintenance, Availability

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